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IMPROVING CONSISTENCY OF SASKATCHEWAN-PRODUCED STRAWBERRY CROWN QUALITY

Funded by:
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Improving the Consistency and Quality of Saskatchewan Produced 'Camarosa' Strawberry Crowns

Funded By:
Agriculture Development Fund (ADF)

Final Report, March 2004

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Abstract

To maintain and extend current export sales of Saskatchewan-grown crowns to California fruit growers, high quality crowns must be consistently produced. The objective of this study is to determine when 'Camarosa' strawberry crowns should be dug in the fall to consistently optimize Saskatchewan crown quality. In order to achieve this objective, the components conferring the Northern Vigour® response must be clearly articulated with a better understanding of the parameters regulating this response. Since the Northern Vigour® response is environmentally regulated, the following parameters will be examined: a) photoperiod; and b) temperature. In this study, "high quality" strawberry crowns is defined as crowns which express high numbers of early flowers. The most critical yield component in strawberry is the number of functional, differentiated floral buds. Floral bud induction and differentiation is considered to be both photoperiodically and temperature-regulated. Subsequent development of functional floral buds leading to flowering is dependent on the chilling requirement, which is satisfied by low, non-freezing temperatures. Environmental regulation of flower bud induction, differentiation and development are cultivar-dependent. Therefore, studies using strawberry crowns of the mostly widely planted California cultivar, 'Camarosa', will examine:

1) The photoperiod and temperature requirements for floral bud induction and differentiation.
2) The optimal temperature regime to fulfill the chilling requirement.
3) Carbohydrate levels in crowns as an index of subsequent flower number and fruit yield.

Executive Summary

Over the past 6 years, previous research (ADF # 94000236 and AFIF # 97000353) has demonstrated that Saskatchewan-grown 'Camarosa' crowns significantly out-yield California- sourced crowns. Based on this research, a new partnership company was formed in 2000 (The Saskatchewan Strawberry Crown Producers) which planted 100,000 crowns on 10 acres of land with an expected yield of 800,000 crowns. This company pre-sold their crop to California growers at a price 50% above that which California growers normally pay for crowns. The California growers are willing to pay this price if crown quality and yields can be maintained consistently. Until 1999, the fruit produced from Saskatchewan grown crowns have been of consistent high quality and yields. During the 2000-cropping season, Saskatchewan crown yields were lower than California-sourced crowns at all three California testing sites. Since this is the first time that the Saskatchewan crowns did not perform well, it has caused great concern for both the Saskatchewan crown producers and the California growers. It is therefore necessary to determine the components of the Northern Vigour® response both for the long and short-term viability of crown production. Once the components are articulated, a consistently high quality crown can be produced. Markets and pricing are dependent upon demonstrated and consistent crown quality. Saskatchewan will not be able to sell its crowns at a premium price if California growers are not confident of the Saskatchewan-grown crowns ability to produce consistently early-yielding and high quality fruit.

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Fragaria x *ananassa Duch.* var. 'Camarosa' is a relatively new cultivar (first adopted in 1994) that has quickly captured the majority of the crown market in California. It is because of this recent introduction that relatively little specific information exists on this cultivar. 'Camarosa' is classified as a June bearing type and a facultative short day plant (Voth et al., 1994). The critical photoperiod is likely less than 14 hours. Temperatures less than 15°C are also generally required for floral induction in strawberry (Guttridge, 1985). The objective of this study is to determine the photoperiod duration and temperature regimes necessary for floral bud induction and subsequent early yield. This would enable recommendations to be made to Saskatchewan crown growers in terms of when crowns should be harvested to maximize crown quality and early yield for the California fruit producer.

Short day/ warm temperature conditions appeared to induce the greatest number of flowers and yield while long day/warm temperature treatments produced the lowest flower counts. This response appeared to also correspond to NPQ (Non-photochemical Quenching) which is an index of photosynthetic efficiency and heat dissipation. Chilling requirement was not related to yield under the methods used in this study. However, it is strongly suggested that a more in-depth model be developed which utilizes a weighted effect of chilling temperatures on subsequent yield. The quantity of chilling requirement satisfied clearly has effect on increasing the rate of flowering. However, statistical analysis based on the 0-7C model deleted this factor out of the equation and indicated only photoperiod as the primary factor. While shoot fructose content may be a candidate in the flowering response, the HPLC methods required render this test impractical for commercial use.

The accumulated 10 years of California fruit yield data combined with readily available hourly temperature data during crown production at various locations in Sasktatchewan over this past decade should be used to create a new temperature/photoperiod model which will better fit the yield responses observed. Photoperiod is a constant factor in the environment while temperature varies widely between years. Temperature is an easy and inexpensive parameter to measure. If a useful model is developed, growers can easily download their temperature data into a computer program and calculate the time for harvest. This will enable maintenance of consistently high quality strawberry crowns for export.

Technical Report

A. Determining the necessary conditions for floral bud induction, initiation and differentiation of Saskatchewan-grown 'Camarosa' strawberry crowns.

Objective: **To determine the necessary temperature and photoperiod requirements for floral bud induction and differentiation of 'Camarosa' strawberry crowns.**

Background:

In the early stages of plant development, embryo cells undergo division. With further growth and development, cell division and multiplication become restricted to specialized plant tissues. These specialized regions differ slightly and the tissues remain in embryonic character causing the cells to retain their ability to divide (Tilney-Bassett, 1986). These embryonic tissues in the mature plant body are called meristems. The meristematic cells continue to divide resulting in new cells, which are continually added to the plant body. This process of growth and specialization of the cells produced by the meristem is called differentiation (Fahn, 1990). The differentiation of the many cells in the meristematic areas results in the growth of vegetative and flowering shoots (Clowes, 1961). During the plant's transition to flowering, the vegetative shoot apex undergoes a sequence of physiological and structural changes and is transformed into a reproductive apex. This transformation (from vegetative growth to floral induction) is known to be affected by various environmental factors, including daylength and temperature (Raven et al., 1981).

Durner and Poling (1985 & 1988) divided the early stages of strawberry plant development into four processes; induction, initiation, differentiation and development. The leaf is the primary organ that (1) perceives changes in temperature and/or photoperiod and then (2) signals initiation of floral induction followed by flower bud production. This process can be monitored by observing changes in leaf initiation rates (Thomas, 1961a,b; Langer et al., 1964). An increase in leaf initiation rates has been found to coincide with the onset of floral induction (Thomas, 1961). Floral initiation includes the physiological and morphological changes occurring in the meristem upon receipt of the stimulus from the leaf. Floral initiation or differentiation is the development of specific floral organs or of flowers on a single inflorescence and is easily studied by dissection. Development consists of the production of the macroscopic flower cluster and can be monitored under greenhouse or growth chamber conditions

In a study conducted in Norway, yield was negatively correlated with temperatures in August previous to the fruiting year. Yield level was not significantly correlated with meteorological data during flowering and harvesting but climatic conditions during flower induction and differentiation appeared to be more important for subsequent yield (Doving and Mage, 2001). Floral induction was highest under 13.5 hour photoperiod and was reduced under 15 hours under which vegetative growth was poor (Konsin et al., 2001). In that study, branch crown number and runner production were increased under short photoperiod.

Floral induction normally occurs during the fall under shortening daylengths (Fig. 1), but can also be induced by low temperatures (Raven et al., 1981). Saskatchewan-grown strawberry crowns are harvested in late September and shipped to California at that time where they are immediately planted. Flowering and fruiting subsequently occur in November and December with the first fruit harvest in the first week of December.

This part of the ADF study will investigate temperature and day-length effects on strawberry floral bud induction and differentiation for 'Camarosa' strawberry under Saskatchewan growing conditions. 'Camarosa' is a June bearing type of strawberry (Voth et al., 1994). June-bearing types typically require daylengths of less than 14 hours (Guttridge, 1985). However, both species and cultivars vary in photoperiodic sensitivity (Evans, 1969). In addition, the photoperiodic response is modified by temperature. The reduction in temperatures has been found to be as important as short days in flower induction in some cultivars (Hartman, 1947; Heide, 1977). Ito and Saito (1962) and Heide (1977), suggest that temperatures above 16°C and daylength below 14 hours are needed to induce flower initiation. Various temperature regimes in combination with various photoperiods will be tested to determine when induction, initiation and differentiation occur within the 'Camarosa' strawberry plant under both field and growth chamber conditions.

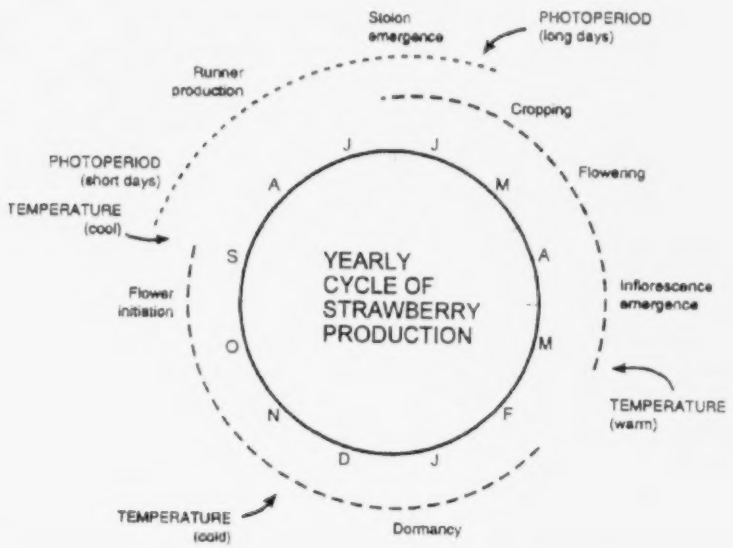

Fig. 1. Growth cycle of strawberry production in Canada.

Hypothesis:

Critical photoperiods in combination with specific temperatures are required for floral bud induction and differentiation to occur in Saskatchewan grown 'Camarosa' strawberry crowns. In previous research, 'Camarosa' crowns typically form runners and daughter plants at the beginning of August and plants are harvested in late September. It is within this time frame that growth is transferred from vegetative to floral induction status.

Experimental Outline:

Growth Chamber Study

Crowns were produced in 4" pots in Sunshine Mix #4 under a 24°C greenhouse under long day (22h) daylight conditions for 8 weeks to ensure the plants were in a vegetative state. Uniform plants were chosen and placed under two temperatures and two photoperiods (2x2 factorial). The photoperiod and

temperature regimes were selected to expose the plants to extreme conditions. Photoperiod at 250 μmol m^{-2} s^{-1} PAR and temperatures of: 1) LD/WT (long day/warm temperature) of 22 h photoperiod and 24C; 2) SD/WT (12 h photoperiod and 24C); 3) LD/LT (22 hr photoperiod and 7C over a 12 h night period); 4) SD/LT (12 h photoperiod and 7C over a 12 h night period) were applied for a period of 4, 6, 8, and 10 weeks. There were 36 plants per treatment. After each period of time, the treated crowns were moved into 4C storage in the dark for 8 days to satisfy the chilling requirement. Plants in pots were subsequently moved into a 22h, 24C greenhouse for a standard period of time (10 weeks) at which time number of scapes (flower stalks), flowers, and fruit were measured. Since crown splitting is of concern to California growers, the 6, 8 and 10 week treatment also monitored this response.

In the second study, six plants were placed in each of the four pre-arranged treatment chambers. One chamber was set at 23/5°C day/night (low temperature) while the other was held at 23/23°C (warm temperature) in the greenhouse. There were also two photoperiods implemented; 22 hour (long day) and eight hour (short day). The long day/warm temperature regime was arranged to run the 5°C low temperature over a 16 hour period, similar to the short day/low temperature treatment.

Four W incandescent lamps were used as light sources set at different times to achieve the desired daylengths in the cold chamber and although the chamber was kept in the dark at all times, extra black plastic was placed around the plants and lamps. A black shade cloth was used to block light in the short day treatment. After five weeks under the respective treatments three plants from each treatment were placed in the greenhouse, under long day/warm temperature conditions. Flower counts were then taken over eight consecutive weeks.

Three leaves from each of the four treatments from study 5.0 were removed from the plants and used for photosynthetic analysis at 0 and 34 days. Expanding leaves were chosen to maintain consistency in sampling.

Photosynthetic Analysis

The leaves were exposed to a 15 minute dark treatment and the initial fluorescence (F_o) levels were measured using a dim red light adapted at 600Hz. A PAM-2000 modulated fluorometer (Heinz Walz GmbH, Effeltrich, Germany) at room temperature was used to obtain the non-photochemical quenching (NPQ). Saturating pulses of white light applied at 800-ms in the dark adapted state followed in order to obtain the Chlorophyll fluorescence levels at their maximum state (F_m).

Light adapted chlorophyll fluorescence was determined by superimposing 1400μmol photons $m^{-2}s^{-1}$ with a white light pulsating every ten seconds for four minutes. Data was collected using a laptop computer in conjunction with the PAM-2000. The system had the ability to control timing and light source with respect to actinic, pulsating and saturating light levels. NPQ was then calculated using the formula $[F^o_m - F'_m]/F'_m$ as described by Maxwell and Johnson (2000).

Results:

In the first study, short days (12 h) and warm temperature (23/23C) treatment induced the highest number of scapes, flowers and fruit yield in the shortest time of 4 weeks (Figs. 2c, 3). By 10 weeks of exposure, even the long day (22 h) and warm temperature (23/23C) induced an average of 10 flowers per plant (Fig. 2a). Nevertheless, floral induction and fruit yield were highest under short day conditions. Low temperature did not appear to influence floral induction since the long day/low temperature treatment did not produce high early floral counts (Figs. 2b, 3) and was lower than the long day/warm temperature treatment (Fig. 2a).

The second study reconfirmed short day/warm temperatures to be the treatment which induced the highest number of flowers (Figs. 4, 5). However, low temperatures were also effective in inducing florigenesis (Figs. 4, 5) in that equal numbers of flowers were produced under long day/low temperatures and short day/low temperatures. Both of these treatments produced higher number of flowers compared to the long day/warm temperature treatments.

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Since photoperiod appears to play a role in florigenesis, and since the leaf is the primary photoreceptor, the efficiency of photosynthesis as examined by electron flow through photosystem II and I (PSII and PSI) was determined under long day/warm temperature, long day/low temperature, short day/warm temperature and short day/low temperature conditions. Non-photochemical quenching (NPQ) provides an index of the fluorescence emitted as heat (Maxwell and Johnson, 2000). The short day/warm temperature treatment which also induced the highest number of flowers had the highest NPQ measurements while the long day/warm temperatures which produced the lowest flower counts also had the lowest NPQ (Fig. 6). Since reactive oxygen species (ROS) can be induced if an excess of electrons in PSII occur which are not dissipated as either heat or fluorescence, higher NPQ may indicate a greater ability to avoid oxidative stress through inhibition of ROS production.

Fig. 2 a. Scape, Flower and Fruit Number per plant Under Long Day/Warm Temperature Conditions

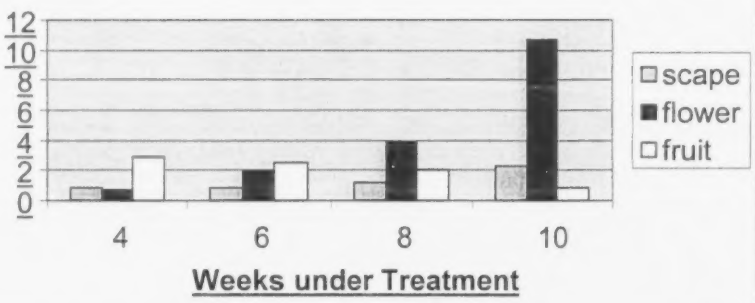


Fig. 2b. Scape, Flower and Fruit Number per plant under Long Day/Low Temperature Conditions

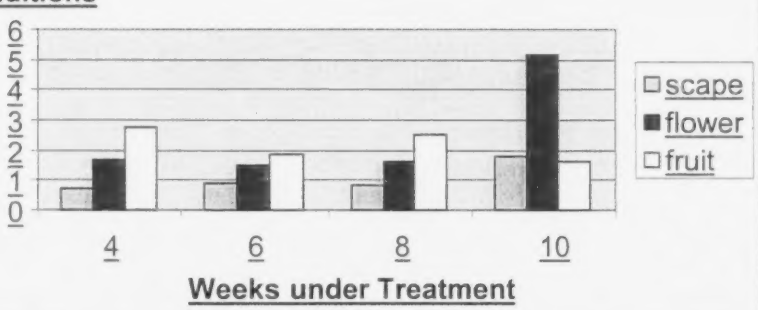


Fig. 2c. Mean Scape, Flower and Fruit number per plant under Short Day/Warm Temperature Conditions

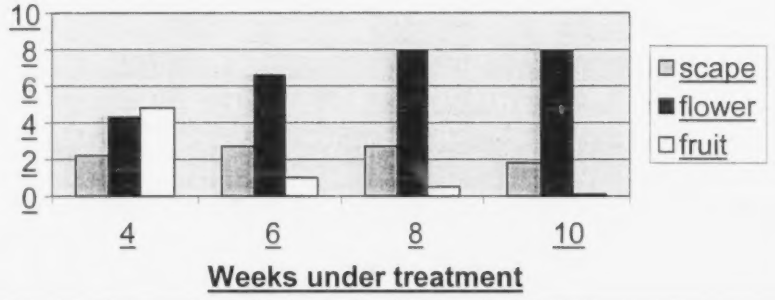


Fig. 2d. Mean Scape, Flower and Fruit Number per plant under Short Day/Low Temperature Conditions

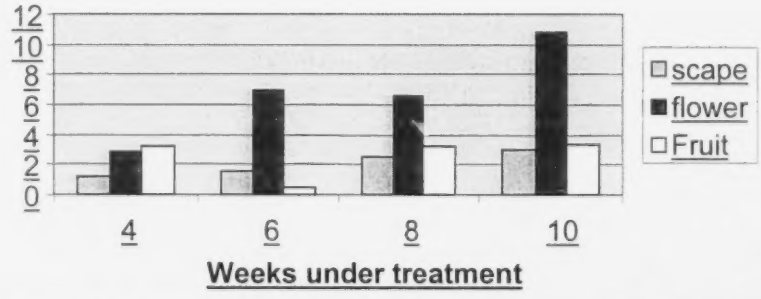


Fig. 3. Scape, Flower and Fruit # per plant Under A) Long Day/Warm Temperature; B) Long Day/Low Temperature;
C) Short Day/Warm Temperature; D) Short Day/Low Temp.
For 4, 6, 8 and 10 weeks.

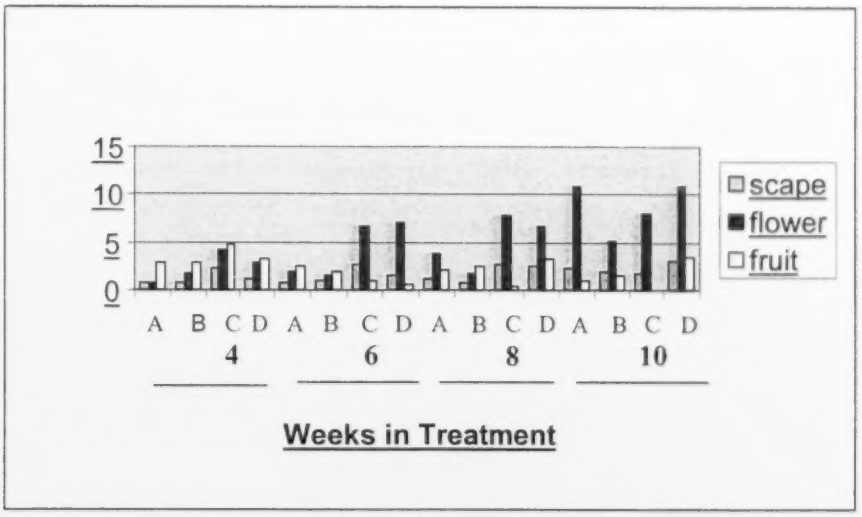


Fig. 4. Study 2: florigenesis under photoperiod and temperature combinations

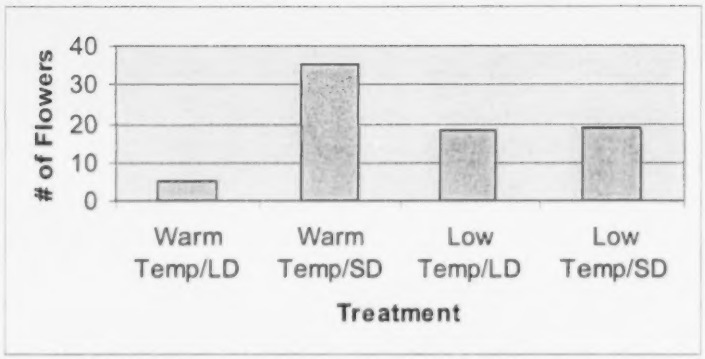


Fig. 5. Study 2: flower production by month under various photoperiod and temperature regimes.

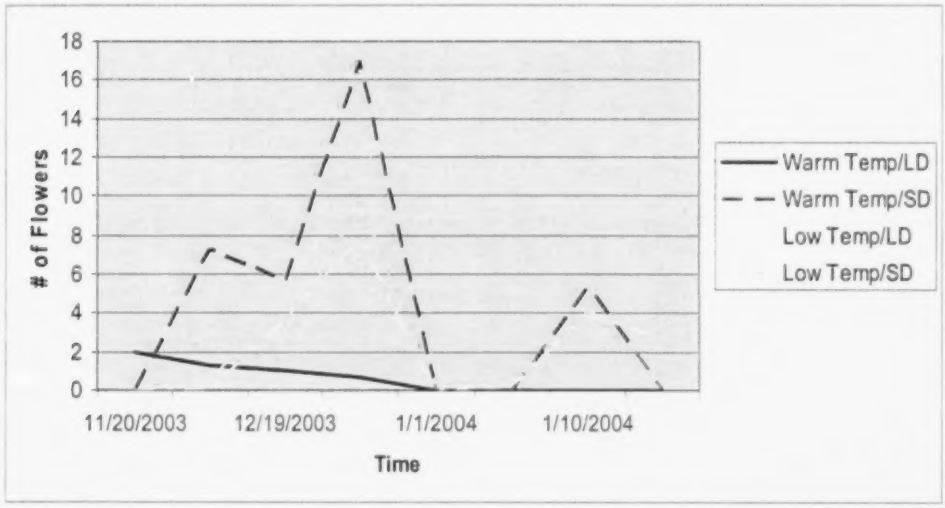
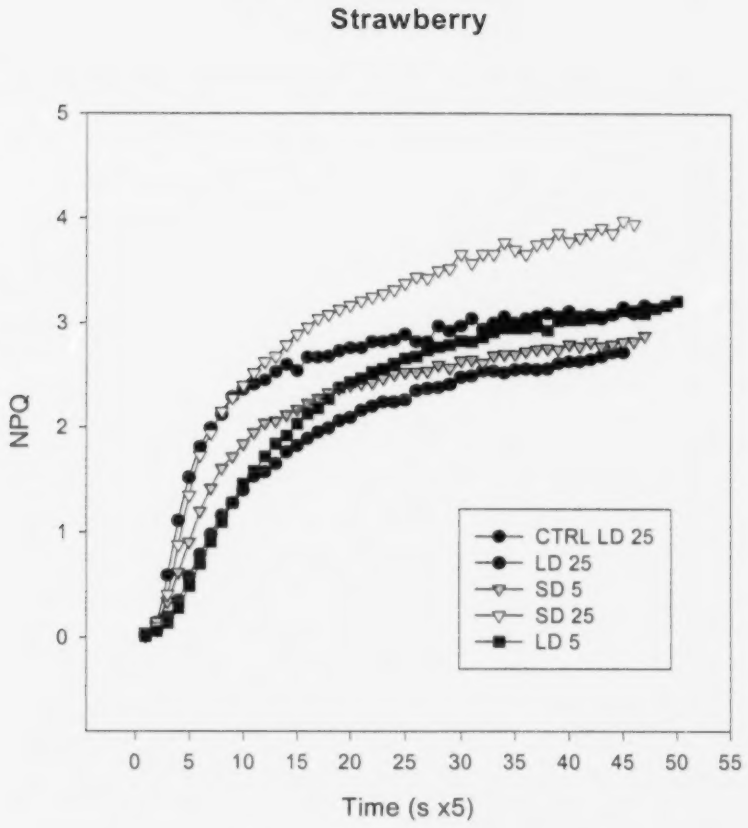


Fig. 6. Non-Photochemical Quenching (NPQ) of 'Camarosa' strawberry leaves when grown under various photoperiod and temperature regimes measured at 0 (Ctrl LD 25) and 34 days of treatment.


Strawberry
NPQ
Time (s x5)
CTRL LD 25
LD 25
SD 5
SD 25
LD 5
0
1
2
3
4
5
0
5
10
15
20
25
30
35
40
45
50
55

B. Determining the effects of chilling on early flowering and fruit yield.

Objective:

1) **Define what temperature is most effective at satisfying the "chilling" for 'Camarosa'.**
2) **Determine the optimum chilling hour accumulation.**

Background:

Strawberry transplants grown in northern areas of the U.S. or in Canada generally provide greater early fruit yields and similar or greater total yields than those grown in Florida. This is an advantage to the strawberry grower in Florida because fruit prices are highest during the early part of the season and then erratically decline as the season progresses (Albregts et al., 1994). A similar situation exists in California whereby earlier fruit equates to higher prices. It is therefore necessary to determine the effect of chilling on 'Camarosa' to produce strawberry crowns of maximum fruiting potential for shipment to the U.S.A.

The chilling history of strawberry crowns affects both the growth rate and strawberry performance (Bringhurst et al, 1960 and Guttridge, 1958). If the plants fail to receive enough chilling, they lack vigour and will not grow rapidly enough to produce an early fruit crop. If they receive too much chilling, they will be overly vigorous producing runners instead of fruit (Bringhurst, 1970; Smeets, 1982; Yanagi *et al.*, 1992). Avigdori (1979) indicated that chilling inhibited the appearance of inflorescence that were not differentiated before chilling started. However, chilling did not inhibit and at times slightly enhanced the appearance of inflorescences, which were differentiated prior to chilling. Bringhurst (1970) found that chilling was necessary for acceptable fruit yields to occur and that the duration of the chilling period for a given variety was directly associated with the length fruiting period.

Chilling hours are calculated as a summation of the number of hours where the temperature drops below a set point. Durner et al., (1986) defined the set chilling point in strawberries as the number of hours at or below 4.4°C. Risser *et al.*, (1992) defined chilling as temperatures below 8°C, while Lieten *et al.*, (1997) defined it as 6°C. These suggested temperature guidelines for chilling requirement were for various strawberry cultivars. Iyer (1975) tested five strawberry cultivars and found that chilling increased flowering and yields in certain cultivars, while others were adversely affected.

Hypothesis:

Chilling temperatures of 0°C to 7.0°C will be most beneficial to estimate subsequent yields.

Materials and Methods:

Chilling hours were calculated based on the number of hours of chilling accumulated between 0°C to 7.0°C at various Saskatchewan locations between August and September. Data was collected over a period of years and correlated with known subsequent yields at a particular location in California.

Results:

Table 2 indicates previously collected chilling data (summation of temperatures between 0-7°C). From this table, the optimum number of chilling hours is unclear where high yields were detected under

as little as 126 hours while poor yields were found under chilling units over 200 hours. Furthermore, a correlation was run between chilling hours and yield using data accumulated from 2000 – 2004 (Fig. 7). Strawberry crowns were produced at Outlook, SK and grown at B&E Farms (Orange County, CA). No significant correlation was found between cumulative chilling hours and fruit yield. While the possibility exists that chilling temperatures are not related to flower number, it is more conceivable that the present model of chilling unit accumulation is inadequate and inaccurate. Day/night temperature differences, and a weighted effect of temperature on yield must be taken into account. For example, a temperature of 4C may be more effective than a temperature of 7C and thus, the model should provide weighted units. Day/night temperature differences have already been shown to be more important in fulfilling the chilling requirement of buds compared to constant temperatures alone (Tanino, 2004).

Table 1. Previous observations of chilling hours (0-7°C) and yields of 'Camarosa' strawberry crowns from Saskatchewan growing in a California.

Crown Source	Fruiting Year	Accumulated Chilling Hours (August and September of the year prior to fruiting of temperatures between 0 and 7C)	Fruit Yield Observations
La Ronge	1998	126	-high/early yields
	1999	212	-fair yields
	2000	no plant material	
Outlook	1999	99	-poor yields
	2000	111	-poor yields
Ile a la Crosse	1999	201	-poor yields
	2000	no plant material	
Meadow Lake	2000	305	-high/early yields
Outlook	2001	104	- high early yields
Outlook	2002	28	- plants died in field
Outlook	2003	214	- high/early yields

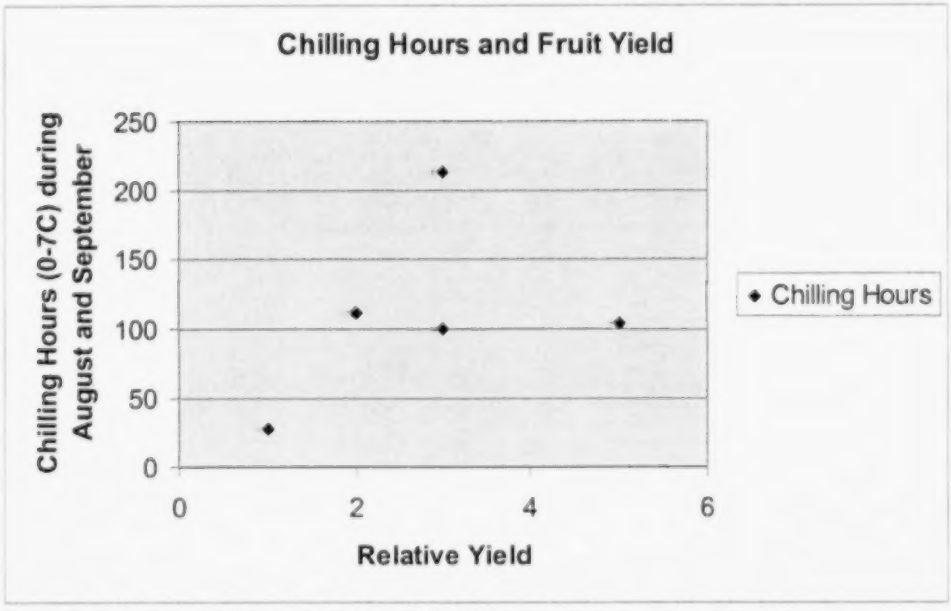


Fig 7. Relative yield ranked according the relative yield of Outlook-sourced compared to California-sourced crowns test at B & E Farms in 2000, 2001, 2002, 2003 and 2004. Chilling hours calculated based on August and September hours accumulated between 0 – 7C of the previous season. 1 = crowns died in field; 2 = poor fruit yields; 3 = yields equivalent to California-sourced crowns; 4 = fruit yield superior to California-sourced crowns; 5 = fruit yield considerably higher than California-sourced crowns.
Correlation: 0.38 and not significant.

Chilling Requirement and Time to Flowering

Previously funded research (ADF # 94000236 and AFIF # 97000353) indicated that Saskatchewan grown 'Camarosa' crowns produced earlier yields when compared to crowns sourced from California. Earlier yields are preferential to the Californian growers, as they are able to receive a higher price for their product in January and early February. The necessary conditions for promoting early flowering is not known. In the previously described experiment the point at which tissue differentiation occurs does not necessarily imply that all conditions have been met for floral bud induction. The objective of this study is to determine what combinations of environmental conditions are necessary for early floral bud induction and to provide a recommendation to Saskatchewan crowns growers as to when the crowns should be dug.

Experimental Study

Strawberry crowns were purchased from Lassen Canyon nurseries in Redding, CA. Crowns were planted at three locations across the province, Outlook (51°. 48' N), Pike Lake (51°. 90' N) and La Ronge (55°. 11' N) on the June 3rd, May 16th and May 29th respectively. All three sites had soil tests collected prior to planting and had nutrients added as were recommended by Enviro-Test Agricultural Services in Saskatoon, Saskatchewan. Plants were planted in a CRD with an inter-row spacing of 30 cm and row spacing of 1.5m. The research plots were maintained following the recommended cultural practices for each region with irrigation occurring throughout the season as necessary. Flower buds were removed during the season to enhance runnering.

Strawberry crowns were dug at weekly intervals from September 6th until the 25th of October. The study consisted of four replicates with five plants each (Figs. 8, 9). Crowns were trimmed (leaves were removed) and planted into 4" pots filled with SunShine Mix #4. Plants were grown in the Agriculture Greenhouses with conditions set to 16 hour days with 22°C + 2°C day and 16°C + 2°C night temperatures. Plants were fertilized weekly with a five 500ppm (500mg/L) of 20:20:20. Data was collected weekly regarding the date of flowering. Pictures were also taken each week for visual comparison. The study was concluded on the 1st of January, 2001.

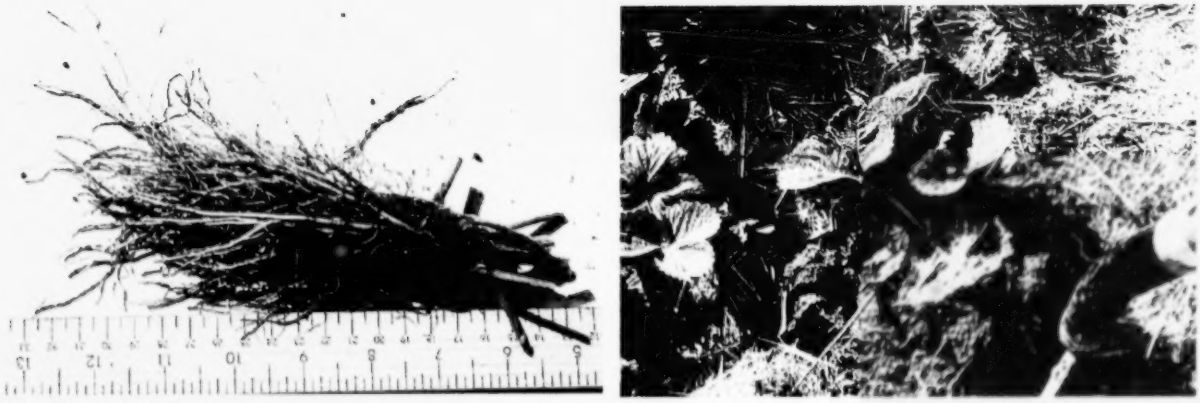


Figure 8. Trimmed samples of daughter crowns (left) after being dug (right) at Pike Lake, SK.

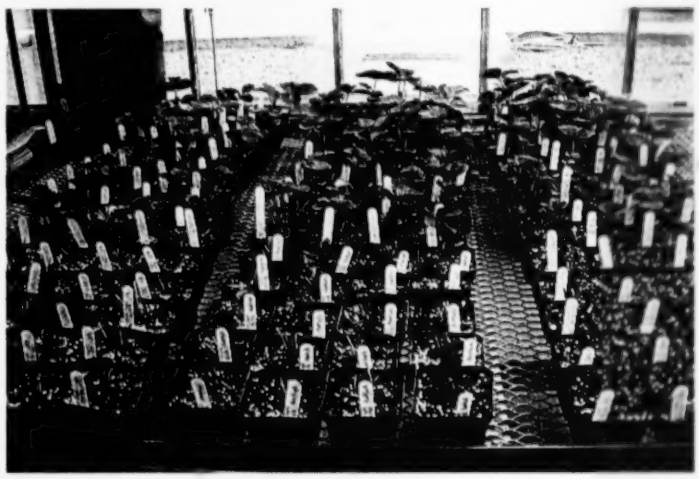


Figure 9. Staggered Harvest Study at the Agriculture Greenhouses, University of Saskatchewan

Hourly field temperatures were taken at Outlook, Pike Lake and La Ronge, to determine the number of chilling hours, which had accumulated prior to each sampling date. Chilling hours were calculated as the sum of those hours between 0-7°C. This was used to compare the number of accumulated chilling hours and the plant response in the greenhouse. As well the day lengths were noted for each harvest date to compare each location, harvest date, the number of chilling and day light hours (Table 2).

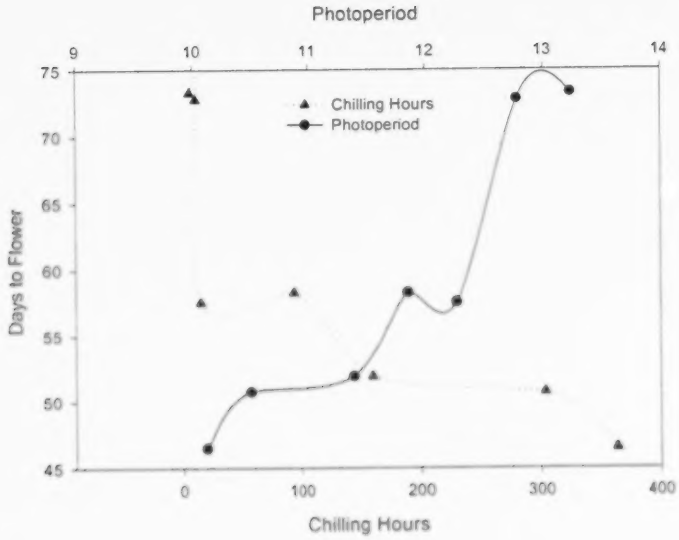
Table 2. Harvest date, days to flower, photoperiod and chilling hours collected from Outlook, La Ronge and Pike Lake

Location	Harvest Date	Days to Flower	Photoperiod	Chilling Hours

Outlook	**Sept. 6**	**68.7**	**13.24**	**32**
	Sept. 13	**67.3**	**12.78**	**55**
	Sept. 21	**55.6**	**12.26**	**95**
	Sept. 27	**57.0**	**11.86**	**213**
	Oct. 4	**48.8**	**11.40**	**270**
	Oct.11	**51.4**	**10.50**	**318**
	Oct.18	**-**	**-**	**-**
	Oct. 25	**48.8**	**10.12**	**481**
La Ronge	**Sept. 6**	**71.0**	**13.38**	**6**
	Sept. 13	**64.0**	**12.78**	**11**
	Sept. 21	**60.5**	**12.26**	**15**
	Sept. 27	**59.0**	**11.82**	**94**
	Oct. 4	**51.6**	**11.30**	**161**
	Oct.11	**52.2**	**10.27**	**304**
	Oct.18	**-**	**-**	**-**
	Oct. 25	**48.2**	**9.76**	**364**
Pike Lake	**Sept. 6**	**66.8**	**13.24**	**43**
	Sept. 13	**57.0**	**12.78**	**82**
	Sept. 21	**52.8**	**12.31**	**117**
	Sept. 27	**47.2**	**11.84**	**204**
	Oct. 4	**46.5**	**11.38**	**255**
	Oct.11	**46.4**	**10.45**	**375**
	Oct.18	**-**	**-**	**-**
	Oct. 25	**44.4**	**10.00**	**440**

Figures 10-12 indicate the relationship of photoperiod and chilling hours to days to flower for each of the three locations. At each location, the days to flower decreases with decreasing day lengths and increasing chilling hours. Statistical analysis was performed using a regression analysis to determine which factors (chilling hours, photoperiod, location or harvest date) had an effect on days to flower. Cooks D and DEFITS was used to removed outliers from the model. Statistical analysis indicated that photoperiod and location had a significant effect within the model on the days to flower ($p \leq 0.01$). Chilling hours were not considered significant. A reduced model regression analysis was then performed with only photoperiod and location. The R square value indicates that these two predictor variables account for a 76.9% fit to the model.

Fig. 10. Chilling hours and days to flower at La Ronge, SK. 2000.


Photoperiod
9
10
11
12
13
14
75
70
65
60
55
50
45
Days to Flower
Chilling Hours
Photoperiod
0
100
200
300
400
Chilling Hours

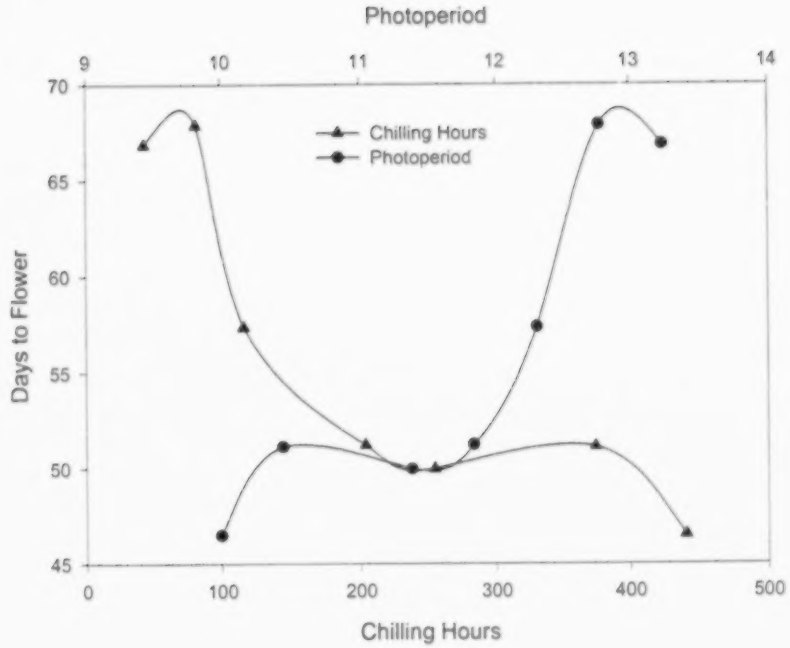
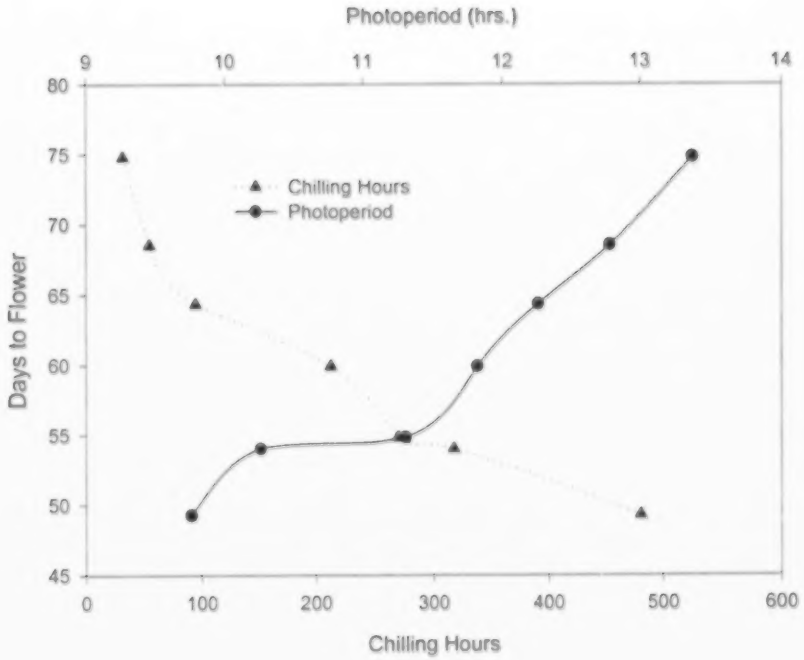

Photoperiod
9
10
11
12
13
14
70
65
60
55
50
45
Days to Flower
Chilling Hours
Photoperiod
0
100
200
300
400
500
Chilling Hours

Figure 11. The effect of chilling hours and photoperiod on days to flowering in Pike Lake, SK. 2000.

Figure 12. The effect of chilling hours and photoperiod on days to flowering in Outlook, SK. 2000.



Early yield has a significant impact on California fruit producer profits since prices are highest in early January and decline at a high rate to the end of January after which the prices slowly decrease over time (Fig. 13). Saskatchewan-grown crowns (planted on October 8, 2003) continue to express a higher, earlier yield compared to California-sourced crowns (planted October 11, 2003) (Fig. 14). If Saskatchewan-grown crowns can consistently induce early, high yields, Saskatchewan will be able to command a premium price on its crown sales. While fruit size based on Saskatchewan-sourced crowns was greater than California-sourced crowns early in the season (Fig. 15), by March 6, fruit size from most sources were equivalent (Fig. 16). Greenhouse-grown plug plant appeared to induce the highest fruit size of all the sites (Figs. 15, 16).

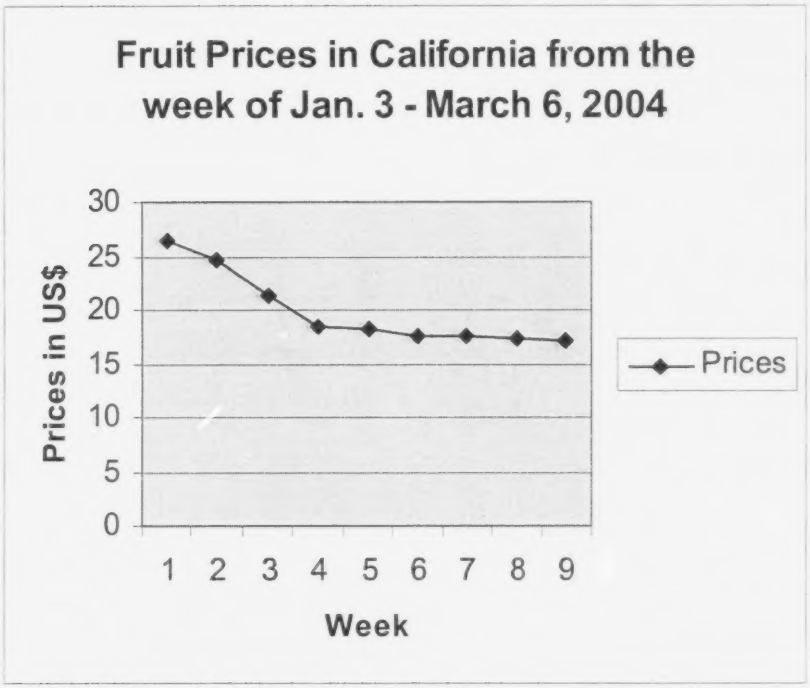


Fig. 13. Strawberry fruit prices (US $) per week per 12 pint tray from January 3 – March 6, 2004.

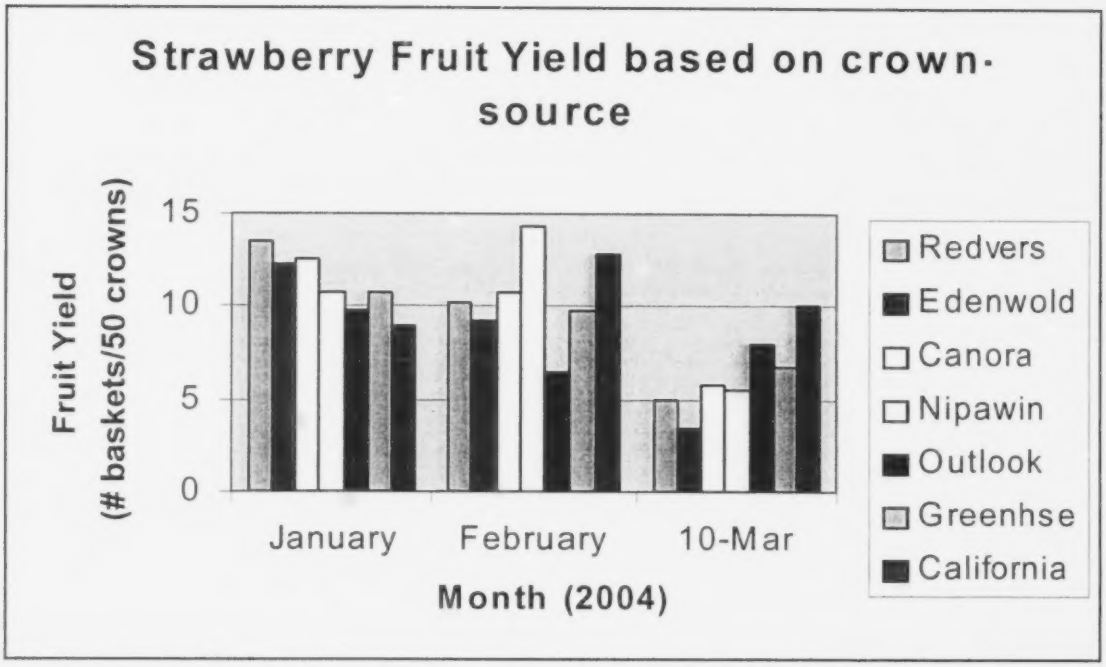


Fig. 14. Strawberry fruit yield at B&E farms, Orange County, CA from various sources of strawberry crowns in Saskatchewan and California.

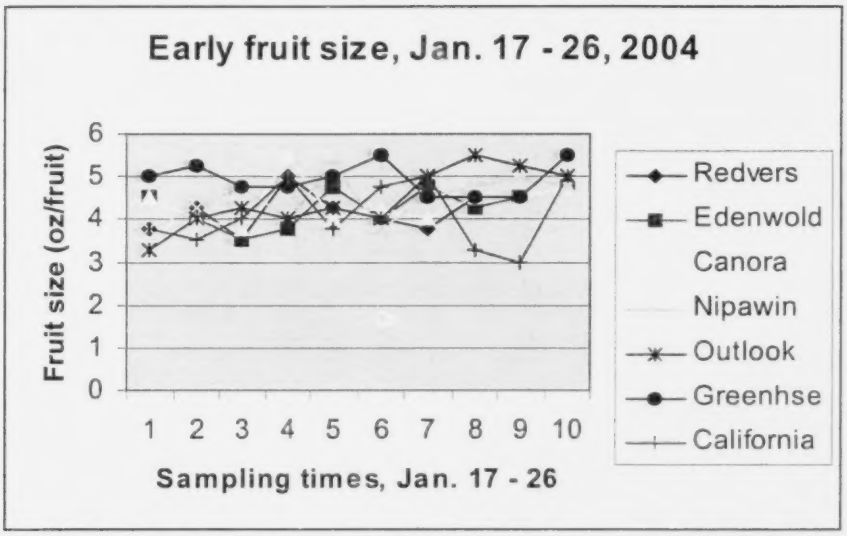


Fig. 15. Early fruit size of plants grown at B&E Farms, Orange County, CA based on source of strawberry crown in 2004.

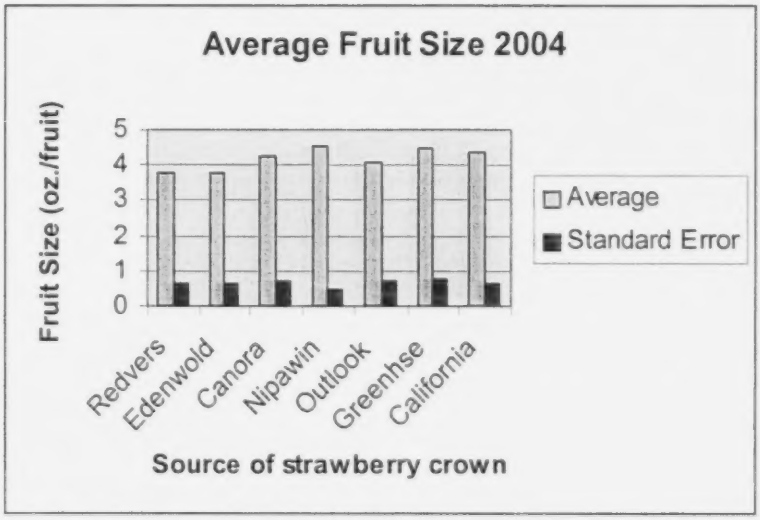


Fig. 16. Average strawberry fruit size at the B&E Farms, Orange County, CA based on source of crown material between January 17 – March 10, 2004.

C. Determining the carbohydrate levels in strawberry crowns as an indicator for digging date.

Objective:

1) To determine if carbohydrate levels vary with treatments inducing flowering.

Background:

Much information exists on factors improving carbohydrate reserves, location of those reserves within the crown and the subsequent effect of carbohydrate reserve levels on crown storage (Bringhurst et al., 1960; Galletta and Himelrick, 1990; Maas, 1986; Mass et al., 1990; Hicklenton et al., 1998). However, comparatively little information is available on its effect on subsequent fruit quality and yield. Lieten (1997) found mixed results where carbohydrate reserve accumulation did not necessarily correlate with subsequent fruit yield. Interestingly, Schupp and Hennion (1997) found subsequent plant establishment was tied to starch and total soluble sugars. Also, previous research conducted by Hicklenton, et al., (1998) indicated that sucrose was the predominant sugar and generally showed the greatest seasonal increase during the fall months. Fructose was found in lower concentrations but also indicated seasonal trends. Starch also had a marked increase within the root.

This study will determine if crown and root carbohydrates (starch, glucose, sucrose, fructose and raffinose – Hicklenton et al., 1998) are correlated with flowering in 'Camarosa'.

Methods & Materials:

Plant Material

From the six replicates in each of the four chambers in study 5.0 the shoots and roots of three plants from each chamber were collected and separated and grouped to their respective treatments to obtain a total of eight samples. The samples were all frozen for six weeks in a –80°C freezer.

Solvent Preparation

The rest of this experiment was conducted in the Food Chemistry lab at the University of Saskatchewan. High-performance liquid chromatography (HPLC) was used to separate the various sugars out of the samples. A two liter solution of 100mM sodium hydroxide (NaOH) was used for the solvent.

Preparation of Standard Solutions

In preparation for the carbohydrate analysis, ten milligrams of each of glucose, fructose, sucrose and sorbitol were dissolved into 100mL of HPLC-grade water. All water for this experiment was purified through a Milli-Q Water System. The sugars were then combined to make one solution. Dilutions of this solution were used to achieve a series of 5, 10, 20, 50 and 100ppm for the four sugars.

Standard curves for glucose, fructose, sucrose and sorbitol were constructed to determine retention times during HPLC analysis. Concentration of monosaccharides in the eight samples was calculated from the standard curves. Statistical analysis of glucose, fructose and sucrose had a correlation coefficient greater than or equal to 0.998 while sorbitol was 0.2393.

Extraction of Monosaccharides

Samples from the freezer were removed and five gram dry-weight subsamples were taken. In order to extract only the monosaccharides, 100mL of 80 percent ethanol was used. The solutions were then heated to 70°C for 30 minutes on a hot plate and stirred occasionally while carbohydrate extraction occurred. Alcohol solutions were then passed through a 0.2μm sterile chromspec NYL filter to remove particulate matter before running through the HPLC device. All filtrate was retained. For each of the extracted solutions a five mg/mL sample was measured into a 10mg/mL syringe and ready for HPLC analysis. In addition, for each solution another five mg/ml sample diluted five times was also used.

Separation of Carbohydrates

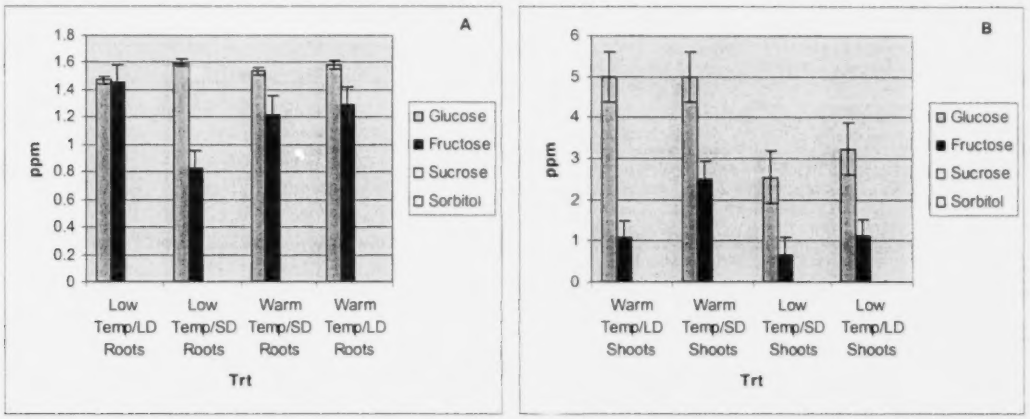
Monosaccharide separation was achieved using a Dionex 10m Carbo Pac PA1 pellicular anion exchange column (4 x 25mm). The carbohydrates were analyzed on a Dionex Bio LC 4000 gradient. The flow rate of 1.0 mL/min was employed and sugars were detected by a PAD (pulsed amperometric detector). Carbohydrates eluting from the column were recorded by a Spectra Physics model 4290 integrator. Duplicate injections of all samples were completed and the experiment was then repeated using five gram subsamples in the second rep and three grams in the third repetition (due to finite amounts). Between all sample injections, a purified water sample was passed through the column in order to rinse any surplus ions preserved in the column.

Results

Glucose, fructose, sucrose and sorbitol levels in strawberry crowns and roots were compared under LD/warm temperature, LD/low temperature, SD/warm temperature and SD/low temperature treatments. In study A., the short day/warm temperature treatment induced the

highest number of flowers under controlled environment conditions (Figs. 3, 4). Under this treatment, fructose was found to be present in the highest concentration in the shoots compared to other photoperiod/temperature treatments (Fig. 17). Low temperatures appeared to inhibit glucose accumulation within the shoots, or alternatively, warm temperatures appeared to enhance glucose accumulation. In root tissues, all carbohydrate levels were generally lower relative to shoot tissues with short day/low temperatures inducing the lowest fructose content.

Fig. 17. Glucose, fructose, sucrose and sorbitol levels in strawberry crowns and roots under various photoperiod and temperature treatments.



Conclusions

Short day/ warm temperature conditions appeared to induce the greatest number of flowers and yield. This response appeared to also correspond to NPQ (Non-photochemical Quenching) which is an index of photosynthetic efficiency and heat dissipation. Chilling requirement was not related to yield under the methods used in this study. However, it is strongly suggested that a more in-depth model be developed which utilizes a weighted effect of chilling temperatures on subsequent yield. The quantity of chilling requirement satisfied clearly has effect on increasing the rate of flowering. However, statistical analysis based on the 0-7C model deleted this factor out of the equation and indicated only photoperiod as the primary factor. While fructose may be a candidate in flowering response, the HPLC methods required render this test impractical for commercial use.

The 10 years of California fruit yield data combined with readily available hourly temperature data in Sasktatchewan should be used to create a new temperature/photoperiod model which will better fit the yield responses observed. Photoperiod is a constant factor in the environment while temperature varies widely between years. Temperature is an easy and inexpensive parameter to measure. If a useful model is developed, growers can easily download their temperature data into a computer program and calculate the time for harvest. This will enable maintenance of consistently high quality strawberry crowns for export.

Bibliography

Albregts, E.E. and C.K. Chandler. 1994. Effect of transplant chilling and planting date on fruiting response of 4 strawberry clones. Proc. Fla. State Hort. Soc. 107:323-325.

Bringhurst, R.S., V. Voth and D.Van Hook. 1960. Relationship of root starch content and chilling history to performance of Californian strawberries. Proc. Amer. Soc. Hort. Sci. 75:373-381.

Bringhurst, R.S. and V.Voth. 1970. Influence of Nursery Harvest Date, Cold Storage, and Planting Date on Performance of Winter Planted California Strawberries. J. Amer. Soc. Hort. Sci. 95(4): 496-500.

Clowes, F.A.L. 1961. Apical Meristems. Blackwell Scientific Publications Ltd. Oxford. 1961.

Doving, A. and F. Mage. 2001. Prediction of strawberry fruit yield. Acta Agriculturae Scandinavica. Section B. Soil & Plant Science 51 (1): 35-42.

Durner, E.F. and E.B. Poling. 1985. Comparison of Three Methods for Determining the Floral or Vegetative Status of Strawberry Plants. J. Amer. Soc. Hort. Sci. 110(6):808-811.

Durner E.F. and E.B. Poling. 1988. Strawberry Developmental Response to Photoperiod and Temperature: A Review. Advances in Strawberry Production. 7:6-15.

Evans, L.T. 1969. The Induction of Flowering: Some Case Histories. Cornell University Press, Ithaca, New York.

Fahn, A. 1990. Plant Anatomy, 4th Edition. Pergamon Press.

Galletta, G.J. and D.G. Himelrick. 1990. Small fruit crop management. Prentice Hall, New Jersey. 602pp.

Guttridge, C.G. 1958. The effect of winter chilling on the subsequent growth and development of the cultivated strawberry plant. J. Hort. Sci. 33:119-127.

Guttridge, C.G. 1985. Fragaria x ananassa. In: A.H. Halvey (ed.) CRC Handbook of Flowering. Vol III. CRC Press, Boca Raton, FL. pp:16-33.

Hartman, H.T. 1947. The influence of temperature and photoperiod on flower formation and runner production in the strawberry. Plant Physiol. 22:407-420.

Heide, O.M. 1977. Photoperiod and temperature interactions in growth and flowering of strawberry. Physiol. Plant 40:21-26.

Hicklenton, P. R. and J. Y. Reekie. 1998. Fall digging date influences carbohydrate content, root respiration, and post-storage quality of strawberry plants. Adv. Strawberry Res. 17:25-40.

Konsin, M., I. Voipio and P. Palonen. 2001. Influence of photoperiod and duration of short-day treatment on vegetative growth and flowering of strawberry (Fragaria X ananassa Duch.). J. Hort. Sci. & Biotechnol. 76 (1): 77-82.

Jonkers, H. 1965. On the flower formation, the dormancy and the early forcing of strawberries. Mededelingen Landbourwhogeschool Wageningen 65:1-59.

Ito, H. and T. Saito. 1962. Studies on the flower formation in the strawberry plants. I. Effects of temperature and photoperiod on the flower formation. Tohoku Journal of Agricultural Research. 13:191-203.

Iyer, C.P.A. 1975. Effect of short duration chilling on the performance of strawberry. Indian Journal of Horticulture. 32: 1-2, 31-32.

Langer, R.H. and Bussell, W.T., 1964. The effect of flower induction on the rate of leaf initiation. Ann. Bot. N.S., 28:103-107.

Lieten, F. 1997. Relationship of digging date, chilling and root carbohydrate content to storability of strawberry plants. Proceedings of the 3rd International Strawberry Symposium. Acta Horticulturae 3439 vol. 2, pp: 623-626.

Lieten, R., van der Scheer, H.A.T, and J. Dijkstra. 1997. Relationship of digging date, chilling and root carbohydrate content to storability of strawberry plants. 439: 623-626.

Maas, J.L. 1986. Photoperiod and temperature effects on starch accumulation in strawberry roots. Adv. In Strawberry Production. 5:22-24.

Maas, J.L., R.J. Griesback and G.J. Galletta. 1990 Changes in strawberry leaf flavonoid pigment composition: an indicator of plant dormancy status? Adv. In Strawberry Production. 9:28-30.

Maxwell, K. and G. Johnson. 2000. Chlorophyll fluorescence----a practical guide. J. Exp. Botany 51(345): 659-668.

Muyzenberg, E.W.B. van den. 1942. The influence of light and temperature on the periodic development of the strawberry and its significance in cultivation. Mededelingen Landbourwhogeschool Wageningen 37: 1-160.

Raven, P.H., R.F. Evert and H. Curtis. Biology of Plants. Worth Publishers, Inc. New York, NY. 1981.

Risser, G., Robert, F., Mass, J.L., and Galletta, G.J. 1993. What cold treatments promote growth in strawberry? Acta-Horticulturae 348:381-383.

Schupp, J. and B. Hennion. 1997. The quality of strawberry plants in relation to carbohydrate reserves in roots. Proceedings of the 3rd International Strawberry Symposium. Acta-Horticulturae 439 (2):617-621.

Smeets, L. 1982. Effect of chilling on runner formation and flower initiation in the everbearing strawberry. Scientia Horticulturae 17: 43-48.

Tanino, K.K. 2004. Hormonal involvement in woody bud dormancy. J. Crop Improvement (in press).

Thomas, R.G., 1961a. The relationship between leaf growth and induction of flowering in long-day plants. Naturwis. 48: 108.

Thomas, R.G., 1961b. Correlations between growth and flowering in *Chenopodium amaranticolor*. I. Initiation of leaf and bud primordia. Ann. Bot. N.S., 25:138-150.

Tilney-Bassett, R.A.E. Plant Chimeras. Edward Arnold Publishing. Baltimore, Maryland. 1986.

Voth, V., D.V. Shaw and R.S. Bringhurst. 1994. Strawberry plant called 'Camarosa'. U.S. Plant Patents. May 3rd, 1994. P. 1-3.

Yangagi, T and T. Oda. 1992. Effects of winter chilling and summer temperature on inflorescence and runner production. Journal of the Japanese Society for Horticultural Science. 60(4): 889-895.